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APPLICATION AND EFFECTIVENESS OF PROPHYLACTIC DEVICES IN MODEL EXPERIMENTS

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16. Abstract

Material is presented for evaluating the effectiveness of prophylactic devices intended for maintaining: a relatively high functional level of the cardiovascular system; the nerve and muscle apparatus; and the water and salt status. The effect of the following are analyzed: physical training, lower body negative pressure, regulation of water and salt consumption, pharmacological preparations, and a combination of these. The author points out the need for further research.

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L. I. Kakurin

Experience in examining cosmonauts and carrying out ground testing with modeling of physiological effects which cause weightlessness made it possible to conclude that the most important and regularly repeated manifestations are: a decrease in functional capabilities of the cardiovascular system, atrophy of the skeletal muscular system, breakdown of metabolic processes, statokinetic and other disorders [1, 4, 11-17, 23, 24, 25, 27, 33]. /1*

The main purpose of our experimental studies was, basically, a complex of prophylactic methods and devices capable of maintaining high resistance of man's organism in relation to physical load and the gravitational effect. The problem involved the fact that the recommended complex of prophylactics should be usable and convenient for use by the crew in the flight of spacecraft of the Salyut type. Our report is limited to the presentation of data obtained in model experiments with antiorthostatic (angle - 4°) hypokinesis (ANOH [ANOG, antiortostaticheskaya gipokineziya, antiorthostatic hypokinesis, ANOH]) when using the following method: physical training, the effect of negative pressure on the lower half of man's body (LBNP [ODNT, otritsatel'noye davleniye na nizhnyuyu polovinu tela, negative pressure on the lower body, LBNP]), regulated consumption of fluids with salts, and pharmacological preparations.

In the first stages of studies, the possible prophylactic effect of each of the devices indicated was evaluated; in the second stage, the effectiveness of the complex of prophylactic measures was evaluated.

Effectiveness of Physical Training /2

In the preliminary experiment with a 49-day ANOH with six

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* Numbers in the margin indicate pagination in the foreign text.

test participants, a complex of physical training was worked out on the training mock-up; this made it possible to simulate bicycling, rowing, and also reproduce walking, running and jumping in place (inertia-shock effects). Setting up a training cycle came from the understanding that energy expenditure must not exceed 450 kcal/hr, and the training must include work of the basic muscle groups [28, 31]. The sequence for completing the load was: warm-up, pedaling for 15-17 minutes, rowing - 12 minutes, inertia-shock loads - 15-17 minutes and the concluding part - breathing exercises. Cyclicity was used in the training process: three days of work with varying direction of load (Figure 1 [Figure 1 was not included for translation) and one day of rest (a cycle 3 + 1).

The use of physical exercises made it possible to retain muscle strength of the flexors and extensors (10 groups of muscles were evaluated) and the physical work capabilities of all test subjects with a sample on the bicycle ergometer. Their orthostatic stability, however, was somewhat worse than the initial (table). Biopsy of the musculus soleus showed that the content of sarcoplasmic and contractile proteins was maintained at the initial level as was their enzyme activity [3].

In this way, the use of physical training during ANOH made it possible to retain basic physical qualities: speed, strength, endurance, and also physical work capability; but it did not have a full effect in maintaining orthostatic stability.

Effectiveness of LBNP /3

An analysis of bibliographical data showed that with the help of the LBNP effect, one can successfully have a positive effect on orthostatic resistance of a man who is in hypokinesis conditions [7, 26, 35]; however, collapse often occurs with this effect [18, 29, 30, 35, 36] - an occurrence which is extremely undesirable in conditions of space flight. Before the present studies were begun, it was assumed theoretically that inclusion of

TABLE:

TABLE:

PULSE RATE (PR) AND PULSE ARTERIAL PRESSURE (PAP) IN A VERTICAL POSITION DURING ORTHOSTATIC TESTS CARRIED OUT BEFORE AND AFTER COMPLETION OF A 49-DAY BED REST

(AVERAGED DATA)

GROUP		INDICES									
		Maximum PR			Maximum Increase PR			Minimum PAP			Number of Pre-Collapse Conditions	
		Before	After		Before	After		Before	After		Before	After
CONTROL (p = 6)	M	79	126	+47	25	47	+22	19	18	-1	0	3
	±	3.1	4.4		3.1	6.7		2.0	1.1			
PHYSICAL TRAINING (p=6)	M	106	114	+8	32	44	+12	18	24	+6	0	1
	±	8.3	5.0		3.2	2.4		4.0	3.1			
COMPLEX PROPHYLAXIS (p=12)	M	98	100	+2	34	31	-3	23	24	+1	0	0
	±	2.1	3.1		2.2	2.8		2.1	1.6			

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a muscle pump for the legs directly during LBNP training can prevent development of collapse. It was necessary, in the first place, to prove this in practice, and in the second place, to find out whether or not it is possible to guarantee the absence of collapse during the effect of significant (50-70 mm mercury column) low pressures in the persons whose organism had first been detrained by the preceding bed rest. And, finally, dangers were pointed out that drops in pressure which occur unavoidably due to change in the volume of the prophylactic vacuum suit (PVS) [PVK, profilakticheskiy vakuumnyy kostyum, prophylactic vacuum suit]) with motion of the legs, involves dehydration of the organism and orthostatic instability.

In the experiments with ANOH lasting 14 days, with 24 persons participating, full retention or restoration of orthostatic stability was not successfully achieved; however, with all LBNP training procedures in PVS [5], it was considerably better than in the control group [10].

In similar experiments lasting 49 days in three test subjects in the same circumstances, when training with the LBNP was conducted for 28-30, for 47-49 days, for 4-5 sessions lasting one hour, a certain positive result was achieved [21]. With /4
maximum values of low pressure (to 75 mm mercury column), which were accompanied by obligatory motion of the legs simulating walking in a rhythm of 10-20 steps per minute, the test subjects continued to feel better even than those who had, during their functional samples with the NPLB fallen into a presyncopal state with "static" pressures 40 or 50 mm mercury column. In these experiments, it was shown that during training with LBNP, generation of water and sodium truly decreased and that the largest effect was achieved in two-day training. In this time period, the size of excretion of fluid in relation to its intake amounted on the average to 43%, and sodium 65% with 75% and 89% in the samples taken the day before. A positive 24-hour balance was

maintained for a 3-day training period; however, a certain increase in excretion of water and sodium was observed in comparison with the preceding day [29]. The data obtained made it possible to modify the method recommended earlier for training with LBNP having supplemented it with its motor activity of the legs at the low pressure level.

Effectiveness of Using Regulated Water and Salt Consumption

In connection with the changes noted after space flights in water-salt exchange reflected in the decreased content of fluids and electrolytes in the organism, an attempt was made to prevent development of a negative water-salt balance by additional introduction of water and salt. Regulated water intake (40 ml of water per 1 kg of body weight) in six test subjects during a 49-day ANOH did not change the general direction of adaptive reactions on the part of water-salt exchange characteristic for hypokinesis. Here only a decrease in the concentration of electrolytes and a slight increase in intensity of diuresis was accomplished. We did not discover any kind of difference in the /5
orthostatic stability of test subjects with regulated or unregulated water intake.

For solving the question of the possibility of improving the reaction to orthostasis and LBNP using an artificial increase in hydration of organism by additional introduction of water and salt, 90 1-3 day experiments were conducted using 10 test subjects on a strictly measured food ration. It was established that the most critically expressed and prolonged prophylactic effect which did not cause any kind of undesirable subjective perceptions, was observed when using dry cooked salt (0.18 - 0.20 g per kg of body weight in 24 hours) fractionally, at the same time as taking food. The salt was dissolved in water or juice in a volume up to 20 ml per 1 kg of body weight in 24 hours (equal portions).

The results of the studies showed that transferability of

the samples with LBNP effect and orthostatic load, after additional introduction of water and salt into the organism, improved significantly (Figure 2 [Figure 2 was not included for translation]). Even after 8-10 hours after the last intake of water and salt, a definite positive balance of water and sodium was noted. Apparently, the reason for the positive effect of an additional introduction of salt and fluid is the increase in the intravascular blood volume, and also the possible effect of sodium chloride on vascular tonus. All of this made it possible to recommend a developed program of water-salt additives for the complex experiment.

Effectiveness of Using Pharmacological Preparations

In the experiments conducted earlier on animals and studies using test subjects [9, 32], from a series of medicinal substances /6 studied, the largest effect on the index of work capability was a mixture consisting of ephedrine and strychnine in pharmacopeia and lower doses with the intended course (5- 10 days). These studies were a precondition for studying the effectiveness of the indicated combination of medicinal preparations in the experiments with a 49-day ANOH on 15 test subjects. The effective doses of the preparation, which were introduced on the background of changed reactivity of the organism without side effects, for ephedrine were 20-40 mg, and for strychnine, 1 mg.

In the conditions of the 49-day ANOH (control-20 prophylactic-6), the preparations were used for 12-14 days beginning with the 35th day. The work capability determined according to P C-170 sample for the 49th day ANOH in test subjects of a control group, decreased by 45%, and in the experimental group by 34% in comparison with background sizes.

The studies conducted made it possible to draw a conclusion as to the principal possibility of correction of breakdown of work capability activity of the cardiovascular system with ANOH using pharmacological substances.

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Results Obtained in Experiments with a Complex Prophylactic

Testing of each of the substances enumerated above separately, and in a number of cases, their combinations, made it possible to theoretically establish a complex of prophylactic substances which, undoubtedly would be required in the experimental testing. In any case, it was impossible, for example, to predict correctly that /7 the combination of water-salt additives and training with the LBNP effect which raised the orthostatic stability, would not have an undesirable effect on the physical work capability in the final ANOH stage. Therefore, these concepts were the basis for two experiments with a complex prophylactic.

Taking into account that in the preliminary 49-day experiment with ANOH, full physical work capability could be successfully retained and muscle strength of the persons examined using the "3 + 1" training complex described above, it was decided that in the complex experiments, physical training would remain unchanged.

In the first of these experiments, the effectiveness of combined LBNP training was evaluated (41 days - 1 hour) and subsequent intake of water and salt according to the system described above on a background of physical training. These substances appeared compatible, did not cause undesirable subjective perceptions and resulted in the significant retention of water and salt in the organism of the test subjects.

In the period of the last (48-49 days) ANOH of this and subsequent experiments with a complex prophylactic, the test subjects were trained in PVS in the morning, alternating then with a simulation of walking in place and jumping (1-2 minutes) with initial low pressure regimes shown in Figure 3 [Figure 3 was not included for translation] (without calculating their variation). After training with LBNP, they received a water-salt additive; in addition, the latter portion of dry salt was administered approximately two hours before the orthostatic sample examination.

The test subjects of the control group underwent considerably more difficult ANOH conditions than did the physical training group. During the next weeks after completion of the 49-day ANOH, they all complained of a general weakness, rapid fatigability /8
and pains in the legs. Even with a small physical load, dyspnoea and tachycardia were observed in them particularly when climbing the stairs even at a slow rate. In a part of the test subjects of the experimental group, 2 - 3 days after completion of ANOH, insignificant pains were noted in the region of the foot and musculus gastrocnemius but completion of the daily physical loads did not cause undesirable sensations.

Orthostatic stability of test subjects in the control group, on completion of the 49-day ANOH, was considerably decreased whereas in groups subjected to the complex prophylactic, it did not differ statistically from the initial for even one of the recorded indices. In this relation, they also differed from the group in which only a single physical training period was used as the prophylactic method (see table). The results of samples with LBNP also attest to the fact that from the 45th to the 47th day of ANOH, that is, before using the equipment intended for maintaining stability toward gravitational redistribution of blood, the reaction of the trained test subjects was noticeably worse than the initial data although better than in the control group.

Muscle strength of flexors and extensors, after completion of ANOH, in the test subjects of the control group was significantly decreased whereas in the group with the complex prophylactic, it remained practically unchanged just as in test subjects who had undergone physical exercise in the preliminary experiment. One can say the same thing about the results of studying the functional mobility and excitability of the musculus quadriceps femoris: these indices in the test subjects of the control group were decreased but in the experimental subjects they were unchanged.

Physical work capability and the functional state of the /9

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cardiovascular and breathing systems of the test subjects of all groups were studied before and after completion of ANOH during the test with gradual increase to maximum load carried out on a bicycle ergometer in a "sitting" position.

The frequency of cardiac contractions at which the test subjects completed work on the bicycle ergometer, after 49-day ANOH, hardly differed at all from the size of the control examination. The volume of work done, the maximum requirement of oxygen and the oxygen pulse, that is the quantity of oxygen used by the organism at maximum load from one systolic heart volume, truly ($P < 0.05$) decreased in the control group whereas, in the groups with physical training and a complex prophylactic, these indices did not differ statistically from the initial indices with a tendency toward increase (Figure 4 [Figure 4 was not included for translation]).

An analysis of bibliographical data showed that the best prophylactic effects were obtained earlier in an experiment with thirty-day ANOH [2, 6] in which a complex consisting of physical training and LBNP effect where the last five days of ANOH was tested. Along with this, it was pointed out that although orthostatic stability and physical work capability in the three test trainees was higher than in the control group, their complete return to the initial level was not successfully achieved [8, 19].

In an experiment with 62-day observation of the test subjects at bed rest, a drop in work capability was successfully prevented; for this, intense muscle work was used, whose cardiac energy consumption amounted to about 1000 kcal/24-hours, and marked decrease in orthostatic stability was prevented [23].

There is proof [34] that the main cause for worsening of physical work capability with long bed rest is a change in the functional possibilities of the oxygen transport system and, in particular, a decrease in productivity of the heart. The role of the antiorthostatic position (-4°) should, probably, be considered minimum inasmuch as it has been pointed out that in practice, /10

one does not note a difference in decrease in work capability and maximum oxygen requirement in test subjects without prophylactic means during the 30 days in strict bed rest with orthostatic (+6°) and antiorthostatic (-6°) positions of the body [20].

Summarizing what has been stated above, one can state that the existence of danger in weightlessness used in experiments with prophylactic devices appeared unfounded. Using this complex, it was possible to not only successfully add these effects produced by physical training procedures worked out earlier, but also to retain orthostatic stability practically at the initial level; these results, before this, had not successfully been achieved by any of the researchers.

Conclusion

In this work, materials were presented on evaluating the effectiveness of prophylactic devices intended for maintaining a relatively high level of functioning of the cardiovascular system, the nerve-muscle apparatus, the hydration and salt status. However, this does not in any way mean that it is desirable to decrease the significance of measures directed at prophylaxis of other undesirable effects of weightlessness. The importance of developing similar measures which have as their goal preventing "motion sickness," disruption of sleep, dysfunction of the digestive system, etc. is completely obvious. Besides, one should note that in test subjects of the experimental groups, a decrease in static endurance of muscles and an increase in excretion of kidney fluids and electrolytes occurred. /11

All of this indicates that many problems and tasks which were present when beginning these experiments have still not been completely solved and the successes achieved must not blind one to the disadvantages and necessity for taking into account, first of all, the difference between a model and actual weightlessness, and in the second place the fact that a given complex can prove to be less than perfect with greater length of ANOH effect.

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